Lee Kuan Yew School of Public Policy
National University of Singapore

Policy Analysis Exercise

Assessing water-energy use inefficiency in agriculture in the upper Syr-Darya River Basin (evidence from Tajikistan)




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Acronyms

KWh	Kilowatt hours
ALRI	Agency on Land Reclamation and Irrigation
MEWR	Ministry of Energy and Water Resources
WUA	Water Users Association
kW	kiloWatt
m^3	Cubic metre
TJS	Tajik Somoni
LCA	Life Cycle Assessment

Executive Summary

Rivalry within the water-energy-food nexus in Central Asia is expected to increase in the long run due to the anticipated effect of climate change on availability of water resources across seasons and geographical locations. In parallel, demand for water, energy and food is increasing as a function of population growth and economic development. The study analyses current state of energy and water efficiency in agriculture sector in the upstream Syr-Darya River Basin of Tajikistan and makes policy recommendations on the required improvements for sustainability of the water-energy-food nexus with the focus on agriculture sector.

Increasing global population has increased the pressure on natural resources like water, energy resources and increased the demand for food. These three sectors have often been studied independently and their interlinkages have been ignored. This has significant implications for results of any policies, proposed in one of the sectors, as causal loops existing in the system may be reinforced. For instance, the study describes how inefficiencies in water use trigger energy use inefficiencies and jointly affect sustainability of the agriculture output. As Tajikistan is highly agrarian in nature, inefficiency in the use of these resources can hamper its economic growth and compromise food security of population.

Through assessment of water-energy-food systems and analysis of water energy use efficiency it was found out that key determinants of the nexus include obsolete infrastructure, low productivity of agricultural sector, highly subsidized water, conventional irrigation practices and electricity supply and low diversification in terms of production of crops (mostly cotton) and electricity generation (through hydro power). Benchmarking the energy use efficiency in comparison to other similar countries, it was shown that Tajikistan was highly inefficient in its production of cotton. Even with the highest yield scenario the energy use efficiency ratio was as low as 0.59. This is much lower than Greece (0.76), India (1.47), Iran (0.62) and Turkey (0.76).

Through primary interviews and analysis of secondary data the PAE was able to demonstrate that the challenges were multidimensional and may need very specific interventions to overcome them. It was found out that both energy and water were highly

subsidized by the government and investments in irrigation infrastructure alone cannot yield the expected results, unless the equity and efficiency of water and energy distribution is taken into account. The report tried to come up with eight recommendations which were then evaluated on the basis on effect and ease of implementation. Post evaluation it was realized that increasing awareness about new technologies, stronger Water User Associations and modernization of irrigation network can go a long way to tackle the existing challenges of the system.

Introduction and Background

In 2014, the International Crisis Group released a report on alarming socio-economic tensions associated with the increasing water stress in Ferghana Valley, the most populous region of Central Asia (International Crisis Group, 2014). The report came in handy and illustrated the interlinkages between different sectors, water users and administrative units in the part of Ferghana Valley located in the Syr-Darya river basin, where water-energy and water-food links are of particular importance. Syr-Darya is one of the main water arteries in the region shared by Kazakhstan, Kyrgyz Republic, Tajikistan and Uzbekistan, and its hydrological basin together with Amu Darya forms the main water body of the Central Asia – Aral Sea (UN FAO, 2014).

Around 90 per cent of the Syr Darya water flow is regulated by reservoirs, which are critical both for delivery of irrigation services to the vast agriculture lands in downstream foothill areas (World Bank, 2004), and electricity production upstream. Tensions between upstream and downstream users over allocation of water resources fueled after the collapse of Soviet Union and emergence of the independent states with differing national priorities (Wegerich, 2004). The 1998 Agreement on the Use of Water and Energy resources of Syr Darya ((ICWC), 1998) provided a framework for energy exchanges in return to water discharges until the early 2000s, but became dysfunctional afterwards (Daryl Fields, 2013). Differing development priorities of the new countries and their rivalry over seasonal availability of water resources became common (Review of the news reports in Central Asia, 2008-2010). The situation exacerbated after the extreme winter of 2008 when the upstream Tajikistan and Kyrgyz Republic were forced to introduce 6-12 hours of electricity cut-offs; due to a low level of water in reservoirs and increased demand for heating (Cummings, 2013). In Tajikistan the situation has been intensified by the disrupted supply of electricity imports after the country was disconnected from the Central Asia Power System.[1] In an attempt to address the problem of seasonal electricity shortages, Tajikistan and Kyrgyz Republic have made incremental efforts to diversify energy sources and reduce predominant reliance on hydropower, reducing energy losses in the system and decreasing demand for energy

[1] In 2008 Uzbekistan made a unilateral decision to discontinue transmission of electricity from Turkmenistan to Tajikistan through its territory. The Government of Tajikistan was urged to introduce strict electricity rationing for rural areas at 2 hours a day, and in the large cities up to 6 hours a day.

through pricing mechanisms (Daryl Fields, 2013, World Bank Press Release, 2013). A series of political commitments to further negotiations on the nexus were made under the frameworks of International Fund for Aral Safety, Eurasian Economic Community, Central Asia Regional Economic Cooperation Forum, Shanghai Cooperation Organization and multiple donor-funded projects of the regional and national scale. However, review of the practical implementation of these initiatives offers very little evidence of success.

The region has an intriguing theoretical hydropower potential, estimated at 971,400 GWh/year (6 percent of total hydropower potential of Asia) (INTPOW. Norwegian Renewable Energy Partners, 2009). Installed hydropower capacity, however, is yet to be developed and is mainly concentrated on Syr-Darya river (Kyrgyz Republic) and Amu-Darya river in Tajikistan (UNECE, 2011; Sorg, 2014; UN FAO, 2014). Nevertheless, only up to 10 percent of the existing potential is realized (UN FAO, 2014). Political decision of the Kyrgyz Republic to develop its hydropower resources through construction of the Kambarata-1 dam on the Syr-Darya's tributary has been initially supported by Moscow and denounced earlier last month due to the disagreements on the financing terms (Information Agency "Vedomosti", 2016). Roghun dam project, initiated by the Government of Tajikistan, have been also stalled due to regional disputes over it potential impact on environment and water allocation. Despite of the recently released results of the World Bank-funded environmental and social impact study and feasibility study for the proposed dam, the Government has not succeeded in attracting funds for the construction phase.

Concerns raised in discussions of the proposed hydropower infrastructure in the region undoubtedly relate to the trade-offs between the priority allocation and use of resources at the regional level. For instance, the argument was made, that amount of water lost in operation of reservoirs through evaporation and seepage, as well as ability to regulate stock and flow of rivers in the upstream countries may result in disruption of irrigation services downstream. The disagreements over allocation and use of water and energy resources at the regional level are heating up (Falyahov, 2015; Evening Bishkek, 2015; International Crisis Group, 2014), while very little is done to explore alternative solutions for adressing the risks of the water-energy-food nexus at the national level (FAO, 2014). This is particularly true for the region's agriculture sector, which provides livelihoods for some 60 percent of population in Tajikistan and Uzbekistan and 40 percent in Kyrgyz Republic. At the same time, agriculture sector plays an important role in ensuring food security of the countries and

accounts for a substantial share of their exports. However, agriculture in the region is largely inefficient, illustrated through low yields, high water and energy intensity and low productivity of labour. In the absence of incentives for efficient water use in the region, the population growth and projected climate processes (World Bank, 2014) reinforce uncertainty in availability of energy and water resource in the medium and long run (Sorg, 2014). Existing regional water sharing agreements and institutions do not encourage Central Asian states to conserve water, and in the current geo-political complexity may be misinterpreted: as countries try to fully utilize their annual allocation of water resource without considering the opportunity cost of its overuse. While in the perceived abundance of water in the region, the upstream countries may have a luxury of being inefficient in their water use; this comes at the high cost to the public sector and environment.

Client organization

In 2014, the UN FAO published a report titled "*Walking the nexus talk: Assessing the Water-Energy-Food Nexus"* (FAO, 2014). The report lays out a framework for better understanding of the interlinkages within the Water-Energy-Food (WEF) triangle and offers a set of tools to evaluate technical and policy interventions. The UN FAO is focused on achieving food security and sustainable agriculture production in the world. Achieving this objective requires careful consideration of the use of resources in the sector, inclusive approach to different stakeholders in ensuring equitable access and availability of food, stability of food supply and its utilization (UN FAO). FAO targets three working areas to identify, assess and manage water-energy-food nexus interactions, namely: a) evidence, b) scenario development, and c) response options. These areas are considered critical in identifying potential impacts of any regulation, a large-scale investment or any other technical or policy intervention.

The water-energy-food nexus has been relatively well described in the region at the macro-level, with a lot of focus on regional cooperation, security and vulnerability (Bekchanov, 2015; Fields, 2013; World Bank, 2004; Sorg&Allan, 2014) context. On the other hand, there are only a few publications examining the nexus from the resource efficiency point of view (Bekchanov, 2015). In their attempt to generate new knowledge on this dimension of the WEF nexus, the UN FAO together with the IFAS and UNRCCA has adopted a scenario thinking strategy in working on the Aral Sea Basin (UNECE, 2015). One of the strategy's

pillars is to build a stakeholders' dialogue for better understanding of the WEF implications beyond the narrow sectors (UN FAO (b), 2014) and building a solid evidence base for development of scenarios and response options. In this effort, the UN FAO has initiated a series of local studies on water-energy-food interlinkages in various countries.

Scope of the study

Our study team partnered with the FAO in conducting analysis of the water-energy food nexus in the agriculture sector on order to create the "efficiency" narrative for all the stakeholders. In addition, the existing literature on resource efficiency in agriculture often disregards the importance of a joint analysis of resources. In the realm of growing population and increasing threats of climate change, improving water and energy efficiency appears to be the most appropriate way of creating additional supply of resources and reducing internal pressure on the production systems of interest.

Following the logic, this Policy Analysis Exercise aims to lay foundation for the broad assessment of the current state of energy and water use efficiency in agriculture production in Tajik part of the Syr-Darya river basin. The report aims to produce evidence base to inform WEF-centric integrated solutions at the local level, and serve as a pilot for further studies to be conducted in the basin. This is very important, as although importance of the nexus-focused policies in the region have been widely recognized, most of the policy recommendations are largely focused on political and regional solutions, hence are not necessarily relevant to the smaller, but more important units of the system – national and local governments, private sector and smallholders.

Research objectives

The report aims to answer the following questions:

- What are the main determinants of water-energy efficiency/inefficiency in agriculture production?
- What are the estimated costs of the inefficiency? Who are the stakeholders sharing the costs?

- What are the prospects of the “business-as-usual” scenario, given the trends of water availability, economic development and population growth in the area of focus? What are the main risks, associated with continuing “business-as-usual”?
- What are the possible technical and non-technical solutions to address the inefficiency?

Geographical area of research

Syr Darya River, also known as a Pearl River,2 originates in the Tien Shan, flows through Kyrgyzstan as the Naryn River and combines with the Kara Darya, originated in the small mountains of Uzbekistan, to create a unified flow of Syr Darya. It flows through the Uzbek portion of the Ferghana Valley on its way to Khujand in Tajikistan and eventually toward the Aral Sea, where it forms a large delta (International Crisis Group, 2014). The total length of the Syr-Darya river from the head of the Naryn in Kyrgyz glaciers to the Aral Sea is about 2,790 km, with the basin area of 150 100 km2. Tajik part of the Syr-Darya river basin is represented by Sugd province, one of the most developed provinces in Tajikistan.

Figure 1. Geographical area of the study

Source: Interstate Commission for Water Coordination in Central Asia. Basin Water Organization "Syrdarya" n.d.

Sugd province of Tajikistan accounts for 12 percent of the total area of the Syr-Darya river basin and 10 percent of its population. The province represents 1.4 percent of the total arable irrigated land directly irrigated from the river basin and generates 1.1 percent of the total annual river flow. Although relative contribution of Sugd oblast to the river basin

[2] Syr-Darya from Persian means “Sir” – “Secret” and “Darya’ – river (comments from the author).

economy does not seem to be significant at the regional level, its importance for the national economy is substantial. The province contributes 32 percent to the total industrial output and 27 percent of the total agriculture production (TajStat, 2014).

Structure of the report

The report is structured in four chapters. The first chapter lays out the analytical framework of the study and provides the background for the research. The next chapter explores the water- energy linkages in the agriculture sector in Sugd oblast. The chapter makes an attempt to understand the present status of the agriculture sector in the area of interest and irrigation as its main input. The chapter sets the stage for further analysis by providing the necessary data points and laying out the key assumptions. Chapter three offers the analysis of energy efficiency in cotton production and benchmarks the findings against the energy efficiency indicator for other countries. Chapter 4 provides an evaluation of the policy options, proposed by different stakeholders to address water and energy inefficiency in agriculture. The evaluation process adopts criteria of water efficiency, energy efficiency and impact on food production, as well as high-level political, technical and financial feasibility assessment.

Chapter 1. Analytical Framework

In 2011, the World Economic Forum identified the Water, Energy and Food Nexus as one of the three most important global risks. The factors contributing to the increased level of risk within the nexus are explained through the forecasted increases in energy and water intensity of food production and bi-directional increases in intensity of water and energy production. The effects may intensify due to population and economic growth along with the environmental pressure on the global system. The challenges may worsen due to governance failures and growing economic disparity across the world. If not addressed these problems may result in escalation of the regional geopolitical conflicts.

1.1. Analytical Framework

Given the complexity of human and institutional interactions effecting the nexus and triggering intensification of feedback loops, Villamayor Tomas (2015) and Scott (2011) suggest to include institutional analysis in the general series of frameworks, that have been used to assess water-energy-food systems. While previous studies, mainly perceived the water-energy-food nexus as an ecosystem, the recent assessments (FAO, 2014; UNEP, 2014) demonstrated importance of the participatory approach and stakeholder analysis in the nexus analysis. This report will adopt a modified nexus assessment 1.0 framework, as suggested by FAO (2014) (Figure 2). The framework is modified to focus on the current inefficiencies in the use of water and energy resources in agriculture at the local level. The general idea of the framework is to structure the assessment along the following pillars:

- The current state assessment of the water, energy and agriculture blocks; interactions between water, energy and food systems;
- Analysis of inefficiency in the use of water and energy resources in agriculture;
- Key stakeholders, decision-makers and user groups and their role and interests in addressing inefficiencies in the use of resources;
- Different sectoral priorities and policies in regard to the use of resources and their effect on each other;

Against this background, the paper proposes a water-energy-food nexus model comprising all important water and energy flows in agriculture production in the area of study. Analysis of the model stocks and flows allows us to identify the key determinants of water and energy inefficiency and match them to the potential policies/interventions required for improving the status quo. Potential effect of the policies targeting specific area is analyzed in regards to their expected impact on the other elements of the nexus. Screening of possible solutions is conducted based on the criteria of their social viability, economic feasibility, institutional enforcement and environmental sustainability as perceived by the stakeholders. Detailed description of the analytical framework is outlined in the Figure 3:

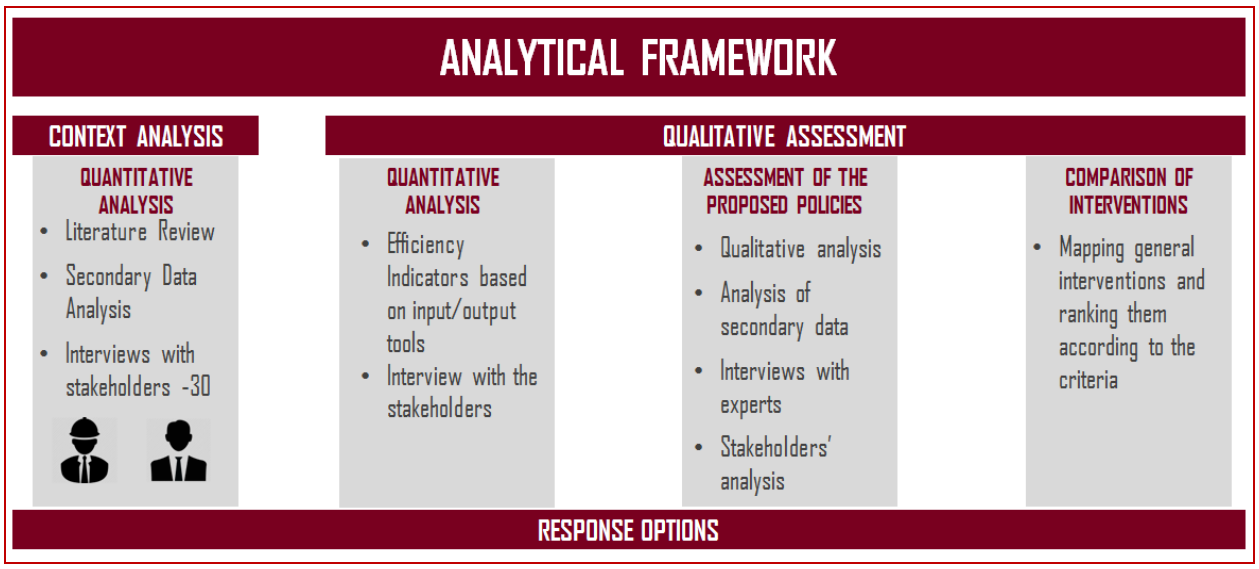

Figure 2. The components of the nexus assessment 1.0

Source: FAO, 2014

1. **Context analysis** was conducted via both primary and secondary research in the area of interest. Interviewers were held with different stakeholders, including: irrigation experts, government officials, farmers, water sector authorities, representatives of think tanks and international organization. The team also consulted the client organization, FAO, both at the land and water division and investment center (TIC). In total, 30 semi-structured interviews were conducted in Dushanbe and Sogd province of Tajikistan. Interviewees were pre-selected, as a result of the initial stakeholders mapping conducted by the team based on the secondary data analysis. Figure 4 includes major groups of stakeholders identified and major blocks of questions, that were used to collect data for the report. The interviews with experts were structured around the following blocks:

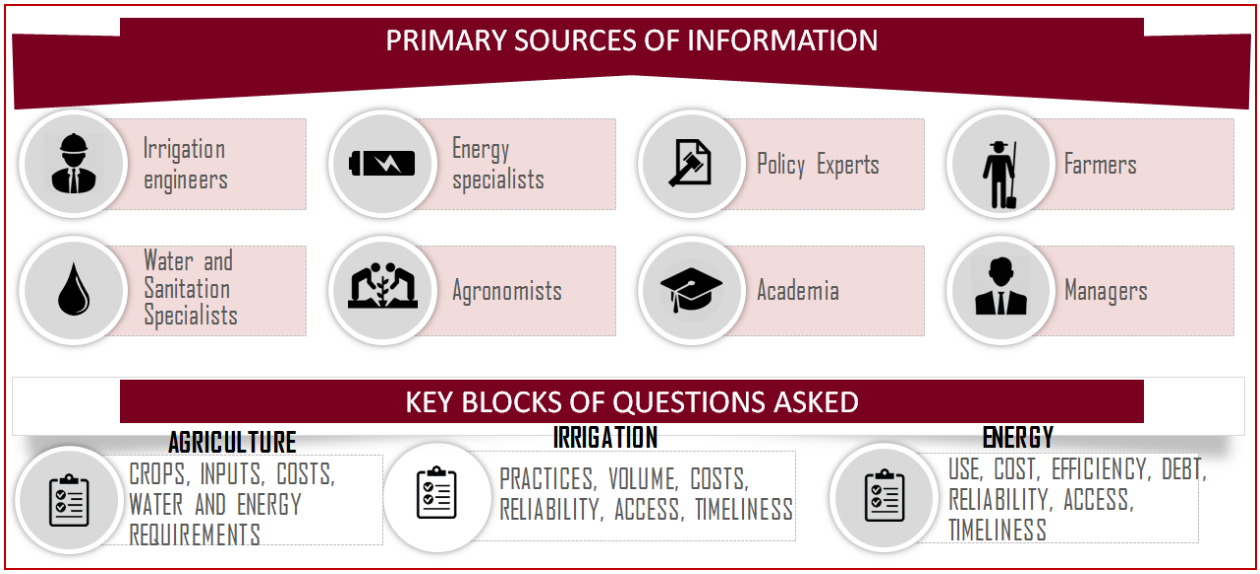

Figure 3. Primary sources of information and categories of questions asked

Secondary information was sourced from the available datasets at the provincial and national level. In addition, the following sources of data to measure the relevant indicators were used:

- FAO Statistical Yearbook, FAOSTAT Database, 2014
- FAO Global Information System, AQUASTAT, 2015
- World Bank Open Data, 2014
- UNECE Statistical Database, 2014
- U.S. Energy Information Administration Datasets
- UNCTAD Statistics
- Statistics Agency under the President of the Republic of Tajikistan

2. Application of input/output analysis. The input-output LCA based analysis was conducted for the main crops (cotton, wheat and apricots) grown in the area with the system boundaries set at the farm level. Life cycle assessment (Walter, 2014) is long known as a tool that starts with defining goal and scope of the process and then proceeds to inventory analysis, optionally continues to impact assessments. The Life Cycle Inventory analysis (LCI) as the "phase of life cycle assessment involving the compilation and quantification of input and outputs for a product throughout its life cycle" (Walter, 2014). LCA allows to quantify the full range of sector-specific inputs and outputs of material flows and assess how these material flows have an impact on the environment. Data availability

and quality are fundamental issues of the LCI analysis. Given the time and budget constraints, detailed primary data were collected from five farms growing different crops to verify secondary information received from the regional statistics. The study also used datasets for the recently completed Rural Investment Climate Assessment Study (World Bank, 2014) and a Baseline Survey for the PAMP II project (World Bank, 2013) for estimating the quantity of agriculture inputs per ha of arable land. The decision to exclude water and energy inputs at the post-harvesting stage was made due to the very low share of agriculture products being actually processed, only about 20 percent (World Bank, 2015). Most of the agriculture products are either sold at the fresh market or exported.

The use of water and energy resource per ha was analyzed and considered for cotton, as the most water and energy intensive crop in the area. The analysis adopted estimates of energy and water equivalents provided in the existing literature in order to quantify the inputs and benchmark the energy use efficiency indicator against other countries. Energy use efficiency indicator was defined as a ratio of agriculture output, measured in kg/ha (converted into its energy equivalent) and agriculture inputs, also measured in kg/ha (converted into energy equivalent). The analysis was meant to seek confirmation of the key determinants of water and energy use efficiency in agriculture production.

3. Analysis of the recent interventions in the agriculture sector from the water-energy perspective. The team has conducted a review of the existing policies in the agriculture sector from the water-energy food nexus perspective. These policies were evaluated on the basis of four criteria: improving water efficiency, energy efficiency, increasing agricultural productivity and understanding financial feasibility.

4. Response options. Based on the findings from the stakeholder's interviews and benchmarking of the, the report will try to suggest policy interventions to address the challenges. Different analytical frameworks for assessment of public policies (Salamon, 2002; Weimer and Vining, 2014) were reviewed by the study team. Given the limitations of data and resources, the framework proposed by the National Collaborative Centre for Healthy Public Policy (2012) was found the most suitable for the analysis of the alternative policies. As the focus of the study is on improving efficiency within the water-energy use in agriculture sector, the framework was modified to suit the research objectives.

Table 1. Criteria for assessment and ranking of the proposed policy interventions

Effects	Criteria	Indicator
	Water efficiency	• Water efficiency indicator • Energy productivity indicator
	Energy efficiency	• Energy efficiency indicator • Energy productivity indicator
	Food production	• Crop productivity • Arable land under irrigation
	Equity	• Access to irrigation water for rural population • Affordability of irrigation services to farmers • Participatory approach in water allocation and management
Implementation	Acceptability	• Political acceptability • Stakeholders acceptability
	Technical feasibility	• Local capacity to implement technical solutions • Access to latest know-how
	Financial feasibility	• Affordability at local level • Affordability at national level

Chapter 2. Water-energy linkages in agriculture production in Sugd oblast

2.1. Assessment of the current status of the agriculture sector

Numerous authors suggest that increases in crop productivity, achieved between the 1960s and 1980s globally, were driven by the extensive use of machinery, intensive tillage, irrigation and chemical inputs (FAO, 1996, Rayner, 2011). This explanation is plausible for the Central Asia Region, where modernization of agriculture practices, application of mineral fertilizers and expansion of areas under irrigation facilitated booming of agriculture production in 1970s. Syr-Darya basin was one of the areas where area of agriculture land under irrigation increased to 130% from 1970 to 1989 (World Bank, 2003). Expansion of

hydraulic infrastructure in the area was initiated as early as during Tsarist Rule, after a decision to develop cotton farming in the region was made. Most of the projects followed by the construction of the first Central Asian Railway, which also connected Sugd oblast to the center. Great Ferghana Canal, one of the last massive infrastructure of 1930s, was built in a strikingly short period of time to bring water to what had been a desert before (Great Soviet Encyclopedia, 1973). Political agenda aimed at reclamation of new land and obtaining "cotton independence" continued after the World War II. Intensification of agriculture was further institutionalized through establishment and strengthening of the state-governed *kolkhozes* and *sovkhozes.* The Soviet agriculture system envisaged that supplies of inputs to and purchases of outputs from collective and state farms were ensured at fixed prices. Measures used in this race for production were largely energy-intensive and levied a heavy toll on natural resources (Sehring, 2009). Centralized public finance allowed the Communist party in Moscow to cross-subsidize agriculture production and utilize comparative advantages, without taking into consideration full social and environmental cost of investment decisions. This had continued until 1990s when the Soviet Union collapsed and shared benefits of the countries were no longer aligned with their national priorities in the market economy.

After obtaining independence and suffering through the civil war (1992-1997), heavily subsidized agriculture sector in Tajikistan was among the most affected. With the collapse of price and supply controls in the agricultural sector, the cost of inputs increased faster than the cost of procurement. Hence, the large farms were unable to purchase at the earlier prices. The demand for fertilizers, pesticides, seeds, and feed fell abruptly, causing a major reduction in the agricultural outputs. Political instability in the region exacerbated the situation and disrupted transport and trade links, making agriculture the only reliable source of livelihoods for growing population. While Sugd oblast was among the least affected during the civil war, due to its isolation, a lot of the factories and agriculture processing facilities closed down, as the production base was not sufficient, new markets had yet to be explored and processing capacity was under-utilized (World Bank, PAD, 2014). Demand for recurrent capital led to selling of farm assets, such as farm machinery and livestock. The use of pesticides and fertilizers converged to zero, as their availability shrank. In the absence of regulations, most of the agriculture inputs were smuggled to Sugd from Uzbekistan.

Infrastructure in agriculture sector was abandoned and went into despair. The situation in Tajik agriculture was also affected by accumulated debts of the cotton farms caused by direct lending and overreliance on intermediaries World Bank, Cotton Sector Recovery Project, 2008).

Structural reforms undertaken by Tajikistan undoubtedly led to some improvements after 1997. One of the major reforms in the country was associated with *distribution of land tenure rights to farmers* (Lehrman&Sedik, 2008; Government of the Republic of Tajikistan, 2011). Transitioning to the new system of individual and family farming was opposed in some parts of the country, as it required strong political commitment from the leadership.

Today, agriculture sector in Sugd province remains a major source of income for rural population. Rural population relies on agriculture, largely considering it as the only social safety net available to them. In 2013, 75% of population of the province lived in rural area and 43.4% of population on Tajik territory were employed in agriculture, forestry and fishery sector (TajStat, 2015). Increased contribution of the agriculture sector to the gross output of the Tajik economy (Figure 3) is largely explained by the improved agriculture productivity in the sector and partially slow development of other industries in the country. The sector displayed substantial growth starting from 2010 (FAO, 2011; World Bank, 2013).

In 2013, arable land under various crops in Sugd oblast accounted for 270,038 ha, Following the appointment of the new Governor in 2013, the land reform has advanced in Sugd province with 60,000 new farms established in less than 1.5 year in 2015(Executive branch of the Sugd oblast) (Figure 4). In average, area of arable land allocated per farm in Sugd oblast in 2014 was equal to 3.2 ha compared to 15 ha in 2010 (Committee of Land Statistics, 2015). Allocation of arable irrigated land has also changed, as illustrated by the line on the Figure 4. Small-holders have become the most important unit of the local agriculture sector.

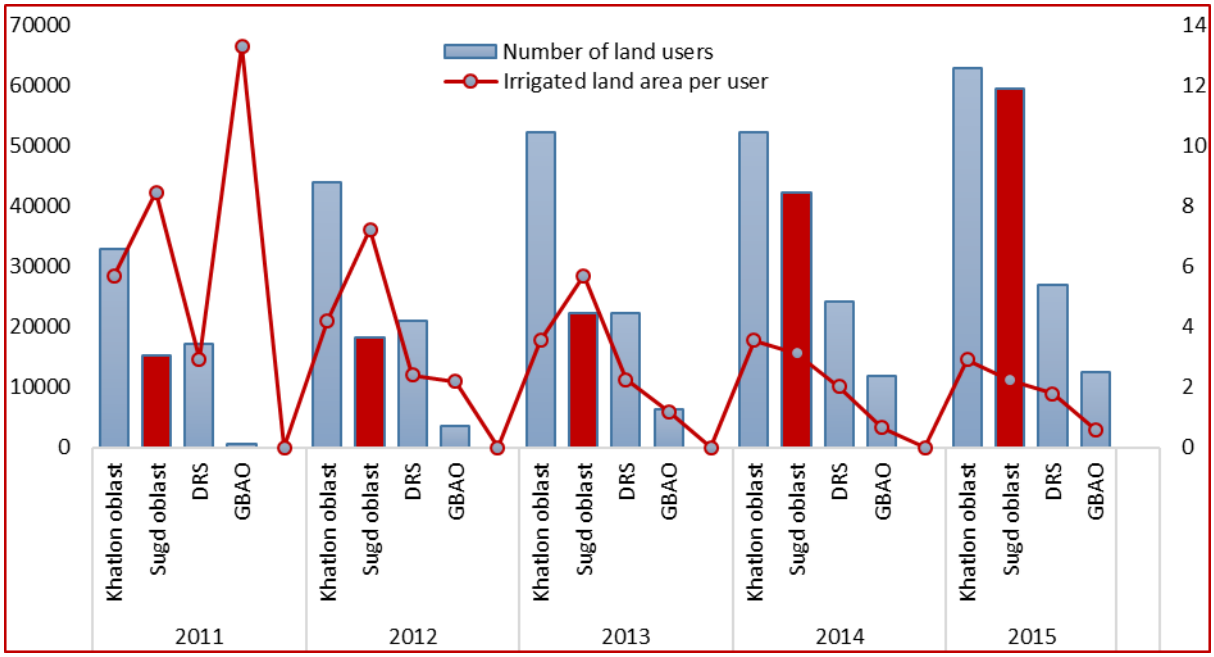

Figure 4. Number of land users in Sogd oblast of Tajikistan and changes in irrigated arable land per land user. Source: TajStat, 2015

Substantial growth in the number of land users in Sugd oblast inevitably effects the use of water and energy resources, as well as implies structural and behavioral changes in the agriculture sector, as discussed later in the report.

2.2. Agriculture Production

Cropping patterns in the agriculture areas of Sugd province differ due to the diverse geographical and climatic conditions of the area. For instance, Zeravshan sub-basin being largely a mountainous region is a major livestock area. Cotton remains one the dominant crop in Sugd province of Tajikistan, contributing 27% of the total cotton output in the country (TajStat, 2015). However, with the decrease in international prices of cotton and improving productivity of farming in the area, area under cotton has been gradually decreasing, while total value of production remained the same (Figure 5).

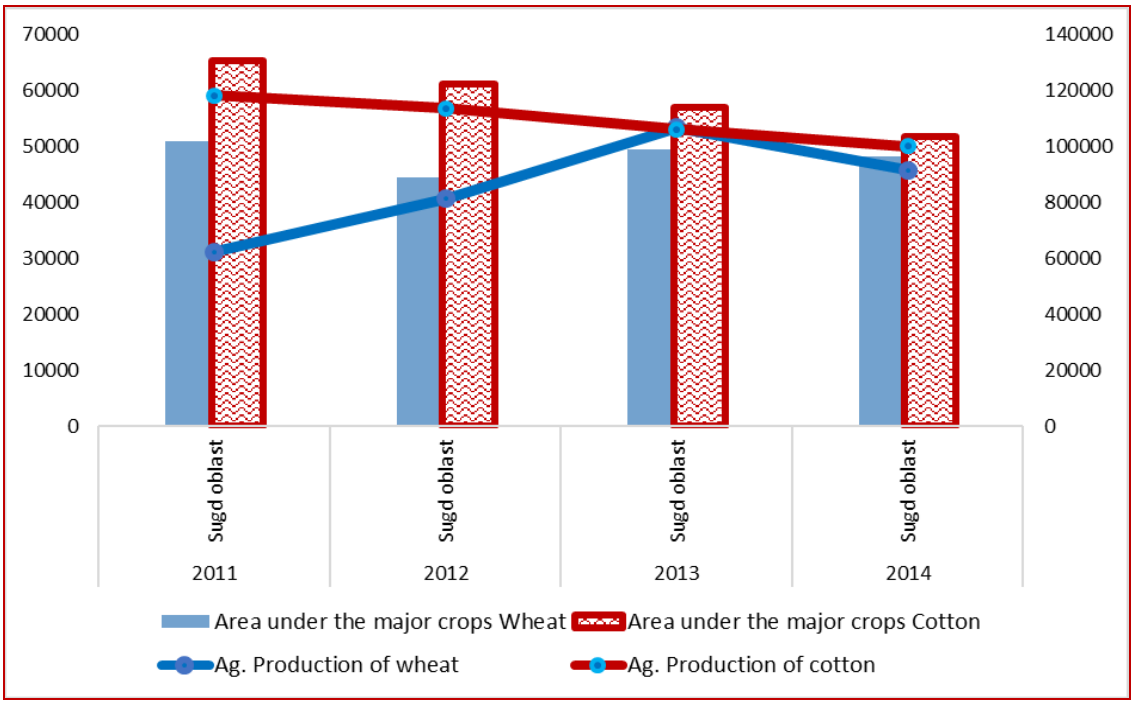

Figure 5. Agriculture production and area under wheat and cotton in tons for the period of 2011-2014.
Source: TajStat, 2015

Grains production has been rapidly increasing in the last decade, as a risk mitigation strategy against disruptions of wheat and flour supply from Kazakhstan. While wheat production is now a pre-dominant crop grown in Tajikistan, production of cotton is still substantial. While cotton remains a major export commodity, its share in foreign revenues has been declining due to a relative increase in other export commodities. However, in Sugd oblast, cotton production is favored by farmers, as it represents the only relatively established value chain. The oblast has also better connectivity to Russia and other Central Asian economies by railway, which reduces transactions costs for agriculture producers (Coulibaly, 2012).

At the same time, agriculture productivity is strikingly low, despite of the favorable climate and availability of water in the main irrigations season, as discussed earlier. Agriculture productivity results also range between the districts in Sugd, for example wheat yields range from 1.3 t/ha in Gonchi district to 3.6 t/ha in Isfara district; productivity of cotton also ranged from 1.4 t/ha in Asht district to 2.1 t/ha in Kanibadam district. In fact, the highest productivity of cotton and other crops was observed in Kanibadam district and Isfara districts.

2.3. Irrigated agriculture

Crop yields on the irrigated land are significantly higher than in the rain-fed areas, for cereal crops it is estimated to be 2-3 times higher (FAO Aquastat, 2013). Reliance of agriculture sector on irrigation makes it the main user of water in the region, with nearly 90 per cent of water diverted for agriculture purposes in Sugd oblast. Irrigated land is a strategically important asset in Sugd oblast, as more than 90 percent of the total agriculture production is grown on it. However, the sector is facing a lot of challenges. Some of the irrigation schemes established once to serve several countries are now in despair and represent a point of confrontation over their operation and maintenance between communities (International Crisis Group, 2014).

Irrigation practices. On-farm networks have been abandoned after restructuring of the large *kolhozes* and *sovhozes* and received very limited attention from the state. Some of the irrigation and drainage canals have not been cleaned for 20 years (World Bank, PAD, 2013). Lack of investments in rehabilitation of the irrigation and drainage networks, as well as traditional water intensive agriculture practices (flooding of the area) resulted in an increase of groundwater table and salinity of soil (MEWR, TajHydroProject, 2011). The scope of services provided by the irrigation sector has also reduced, as most of the on-farm irrigation networks were transferred under responsibility of the farm owners or their associations. At the same time, on-farm irrigation management demanded more sophisticated approach to organization of the sector and its outreach to farmers. Consequently, this led to increased water losses and seepages in the system and inadequate operation of the network. Irrigation efficiency in Sugd province is estimated at about 30 percent, and average annual abstraction for irrigation in the basin is well over 129,000 m^3 per hectare (AquaStat, 2014).

Surface irrigation is predominantly used in the area, requiring farmers to wet the entire field, even if the crop growth covers only spots on it, hence increasing infiltration (ALRI, Interview in Kanibadam, 2016).

Small on-farm pumps. Given higher profitability of the irrigated agriculture, many private farmers invest in small unregulated pumps, affecting fair allocation of water in the seasons of low water flow (early in the irrigation season March-April), and in the areas disadvantaged in their access to water due to the geographical location (tail of the irrigation canal or farmlands located before the large pumps). Small privately operated pumping stations are old and have been in operation for 20 to 25 years. This had increased their wear

and tear levels leading to decrease in efficiency, and it is expected that they would need to be replaced in the near future (Figure 6).

Figure 6. Private pumps installed by the apricot-growing farm in Eastern Kanibadam, Sugd oblast of Tajikistan
Source: Pictures taken during the field trip

Discussions with the farmers located along the Big Ferghana Canal revealed challenges for farmers whose land plots were located just before the large pumping station (Mahram 1). Availability of water in March to May was challenging, as the level of water in Isfara river (tributary of Syr-Darya) was low. Most of the water discharged from the reservoirs upstream was withdrawn for agriculture needs in upstream Kyrgyz Republic and Uzbekistan. In some cases, the farms located along the Big Kanibadam Canal had an advantage, as they could use their private pumps to extract water required for irrigation. However, this would leave farms in the tail of the canal without much water, making an issue of fair water allocation acute.

Use of tubewells for irrigation. Around 6% of arable land in Sugd oblast of Tajikistan is irrigated from tubewells. This practice, not popular in other Central Asian countries due to high concentration of salt and metals in their drainage waters, is helpful to farmers in their attempt to complement supply of irrigation water during the dry seasons. However, volume of water extracted using tubewells is not known, as the owner does not pay for water itself, but only covers the electricity and O&M costs.

Large pumps. The problem of small pumps is easier to solve than replacement and rehabilitation of the massive pumps installed in Soviet times. Irrigation in Sygd province relies on 153 massive pumping stations. Functioning of these pumps is critical to agriculture,

especially in the period when water level in the main magistral canal is generally low, from March to June. During the summer time, the region may not seem like experiencing any shortages in irrigation water, however, it is only a perceived truth. Fourty percent of arable agriculture land, largely in Asht, Kanibadam, B.Gafurov districts use pumps to feed into the large irrigation network. The pumps built as early as in 1960, frequently break and hamper access to water for irrigation, especially in the early periods of land preparation, which are critically important for farming. Irrigation season in Sugd province starts in the end of March-April. Discharges from the reservoirs in upstream Kyrgyz Republic (Toktogul reservoir) are generally restricted during this period, as the level of water in reservoirs is still low. Sugd province receives water from Kyrgyz Republic through the transit agreement with Uzbekistan, which make the negotiations process challenging, involving numerous authorities (ICWC, 2012). Once the temperature increases by the mid-April and inflow increases due to melting of glaciers, discharges from the reservours upstream increase, driving supply of water up.

Pumped irrigation in Sugd oblast of Tajikistan requires more detailed investigation, as its cost structure differs from the gravity irrigation. The system comprises 153 pumping stations with operating in different regimes. These systems established in Soviet times are often referred to as cascades. These cascades are operated to lift water to the height from 19 to 70 meters. Operation of the cascade systems comes at the higher cost compared to the gravity systems due to the greater consumption of electricity and higher maintenance costs. First-hand information was collected on one of the largest pump stations in Sogd oblast to assess the some of the costs related to inefficiency of the system.

Box 1. Key Assumptions and Inputs for Analysis

The current price of electricity charged to the public is TJS 0.12/kWh (Asia Plus, 2015)..
The current price of electricity charged to irrigation sector during the vegetation season is TJS 0.0188/kWh (Asia Plus, 2015).
Estimated annual electricity bill for Mahram station: 11,750,000 kWh (Capacity – 9,600 KW).
The use of pumps during the vegetation season varies across months depending on seasonal availability of water.
Farmers are charged 17.7 TJS/ha (including 18% VAT) for hectare of cotton.
The key crops grown in the area serviced by the selected pumps are: cotton, wheat and apricots as the high value crops.

The levelised cost of electricity in the country was estimated to be as low as USD$0.015kWh or TJS 0.06 (IRENA, 2014). This means that the financial burden on the public sector is substantial. Irrigation departments responsible for operation and maintenance of the pumping stations are largely indebted for their electricity bills, as collected irrigation services fees are not sufficient to cover the electricity costs. Operation and maintenance costs of the irrigation sector are estimated to be 2-3 times higher than those incurred for gravity irrigation. The requirements just for O&M were estimated in 2004 by ADB at US$21-28/ha for gravity systems and US$60-150/ha in pumped systems (ADB, 2005). Some of the irrigation experts we met during the field trip confirmed that collected fees only cover 30 to 40 percent of their annual requirements. This also brings up a question of transparency in the process of irrigation financing. All the farmers pay the same flat rate fee regardless of the type of irrigation they use and their expenditures on irrigation account for less than two percent of their total costs. Differentiation between the pumped irrigation and gravity irrigation land plot is only observed in a different land tax rate applied. However, this difference is also quite small. All the irrigation fees and land taxes collected by different responsible agencies are transferred to the Central Budget, which then allocates certain amount of money for payment of electricity bills, operation and maintenance costs and staff payroll. In its inability to cover the electricity costs, the Government had to write of the irrigation sector debt several times in the past. This practice also severely undermines financial performance of the electricity utility – Barki Tajik. Figure 7 illustrates financial burden of the irrigation sector based on the example of Kanibadam districts. While irrigation fees collection rates in Kanibadam range from 80 to 90 percent, other districts, especially in Khatlon province have much lower fees collection rates. [3]

[3] Interviews with representatives of WUAs in Khatlon and Sugd oblasts in August 2015.

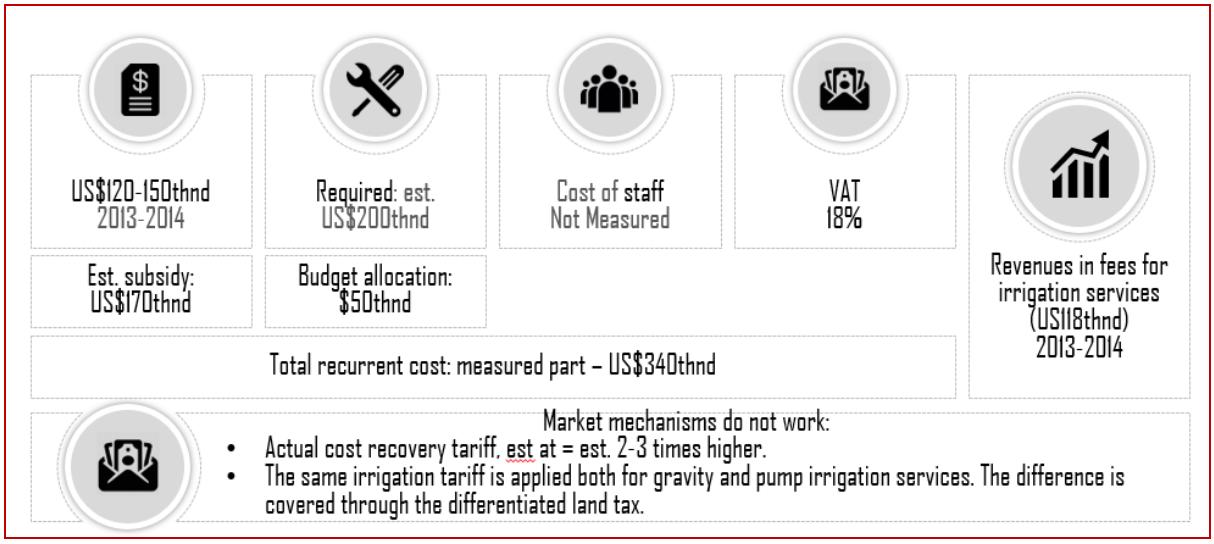

Figure 7. Illustration of estimated costs and revenues of the irrigation sector in Kanibadam district

Water Users Associations. As number of independent farmers increases, complexities of on-farm water management also increases. For instance, collection of irrigation service fees, operation and maintenance of the on-farm irrigation network, distribution and allocation of water, preparation of water schedueles and measurement of water consumption become an unbearable responsibility for the irrigation authorities. The "Water Users Association" Law was enacted in 2006, which laid the foundation for setting up WUAs as "non-commercial organizations providing services for operation & maintenance of irrigation systems for the benefit of water users".[4] Development of WUAs has been supported by the key development partners in the country.

However, WUAs still facing legal, management, operational and budget constraints in its evolution into strong and socially representative organization. Poor condition of the inherited infrastructure is one of the bottlenecks in the WUAs development in the area, as improvement of on-farm irrigation service delivery is associated with relatively large initial investments in rehabilitation of the network. Another challenge faced by WUAs is their dependence, rather than partnership-based relationship with the irrigation authorities on the ground, as WUAs are in many cases purely perceived as agents of irrigation agencies in collecting irrigation fees. Low technical and managerial capacity, as well as limited financial resources also diminish chances of WUAs for success.

[4] Republic of Tajikistan. ""Water Users Association" Law of the Republic of Tajikistan # 387 ." Dushanbe, November 26, 2006.

2.4. Water-Energy-Food Nexus in Sugd agriculture

The relationship between water, energy and food production in Sugd oblast is illustrated on the Figure 8. Availability of water through irrigation dictates the type of crop that may be grown in a region. The water-food nexus is very important in the region due to two major factors: i) changes in water supply patterns, that influence sectors a highly water intensive agriculture, ii) the projected demand for food will increase the competition for limited water resources (IRENA, 2015).

Interlinkage between water and food sectors can lead to multiple challenges and risks. For instance, poor quality of water and obsolete irrigation infrastructure can lead to soil degradation and increased salinity. Also, increased usage of chemicals to produce crops can lead to increase in water pollution, affecting quality of water downstream (IRENA, 2015; Pannier, 2009).

At the same time, water is an important input for energy generation in Tajikistan. Kayrakkum HPP on the Syr-Darya river generates most of the electricity for Sugd region. Seasonal fluctuation in availability of water leads to electricity shortages in winter times. In some years, the electricity cut-offs also affect irrigation sector, as operation of drainage pumps becomes infeasible.

As described in the sections above, the irrigation sector in Sugd region is highly energy intensive. In fact, energy is used at many stages of agriculture production, including land preparation, cultivation and harvesting. With the recent efforts of the Government to incentivize development of agribusiness, consumption of electricity at the agriculture processing stage is expected to increase.

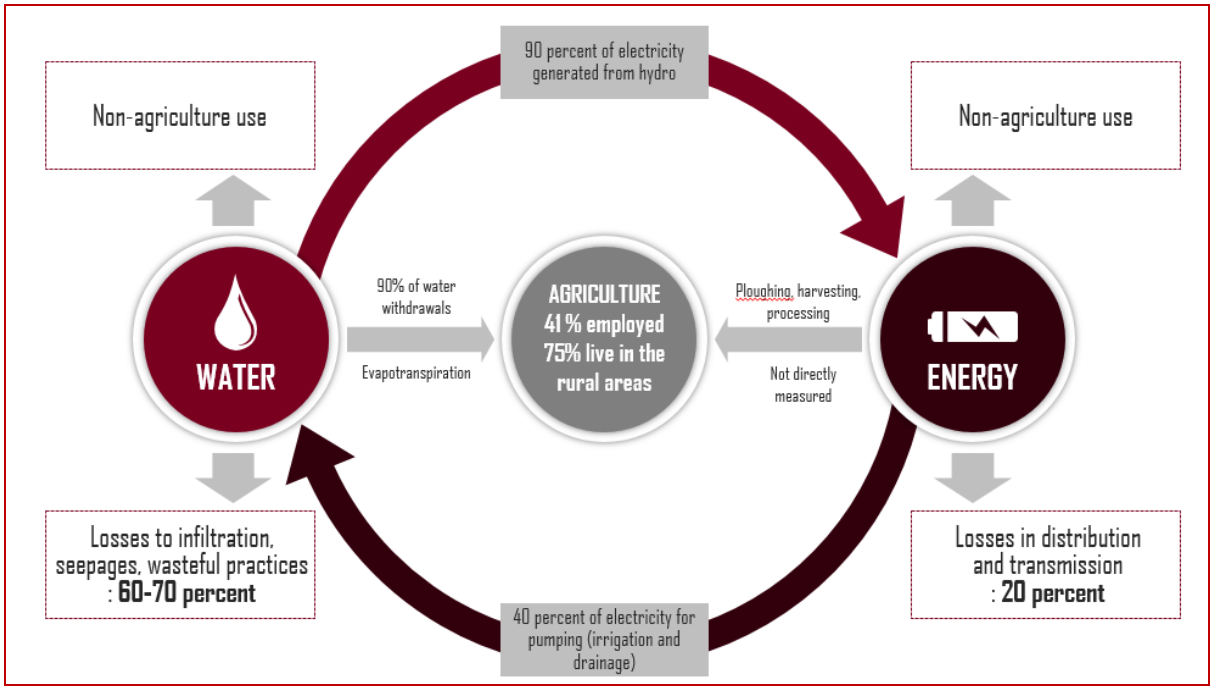

Figure 8. Water-Energy-Food nexus in agriculture sector in Sugd oblast

2.5. Implications of water and energy use inefficiency

The Figure 8 also demonstrates losses of water and energy resources in the system. This inefficiency comes at the very high cost. In Tajikistan, the electricity bill of the irrigation sector in 2012 was estimated at US$7.36 mln, while the total accounts receivable to the Barki Tojik was assessed at US$32 mln., even after the debts write-off in 2008 (ADB, 2012). Given that 30 per cent of the total arable land in the country is pump irrigated, the roughly estimated cost of power for irrigation/ha is US$30/ha; however, this is a highly aggregated figure. More explicit example is provided in the Box 1.

Box 2. Case study: Kanibadam district

Kanibadam district is one of the most productive agriculture districts in Sogd oblast, mainly growing high value crops, such as cotton, fruits (for further processing) and vegetables. The district receives water from the tributary of Syr-Darya river (Isfara river) and Big Ferghana Canal fed from Uzbekistan. Thirty per cent of the arable land in Kanibadam is under pump irrigation (20,000 ha). The district is expected to receive 205 mln m3 of water per year, however it actually receives only 70-75 per cent of the planned amount. There are 176 irrigation and drainage pumps on the territory of the district. 17 WUAs were established in Kanibadam with the average service area of 2500ha-3000ha.

Mahram station is the largest pumping station in the area, which starts its operation in March to pump water from the Kayrakkum reservoir into the Big Ferghana Canal (with the capacity of 15 m3/sec). Individual capacity of each out of six pumps installed at Mahram station is equal to 1600 kW (1.5m3/sec). Total annual electricity consumption of the station is estimated at 11,750 MWh. In total, the annual power bill of Kanibadam averages from US$120,000 to US$150,000.

Around 20 per cent of water is lost in Big Ferghana Canal annually, as some sections of the canal are no lined. During the early months of irrigation March – May, when the level of water in the BFC is very low, the water is predominantly pumped, however only those farms that are located after the pumping station can benefit from the pumped water. Others still rely on the water level in Isfara river, hence reduction of losses in the distribution system could result in better yields for them.

Operation of the pumping station results in huge losses, as current tariff for irrigation services, equivalent to 0.017 TJS/m3 (0.0040 USD) does not cover even 50 per cent of the actual costs of the responsible branches of the ALRI. In 2014-2015, US$144,000 was collected in irrigation fees, while electricity charges for only Mahram station were estimated at US$60,000. In total, debts of the irrigation sector for the electricity company were assessed at TJS702,000, tax debts – TJS 600,000. Public budget allocation could only cover 30 per cent of the annual sector needs.

Opportunity cost of electricity generated in Tajikistan is considered minimal given limited avenues for export of the electricity surplus. However, the recent signing of the power purchase agreement between the Governments of Afghanistan Kyrgyz Republic, Pakistan and Tajikistan is a potential game changer, as it will create a market for summer electricity surplus generated in Tajikistan. The proposed electricity tariff is set at US$0.05 per kWh (CASA-1000). Comparing this tariff to the currently subsidized fee for irrigation pumping equivalent to US$0.0035 per kWh, makes it highly attractive. Policy makers will need to assess appropriate incentives for water and energy savings is agriculture to be put in place in order not to comprise food security situation, but at the same time to ensure the best possible use of the electricity generated.

Chapter 3. Energy and water use efficiency in agriculture

According to the Energy Charter (2013), Tajikistan displays the highest electricity intensity in the Central Asia Region, being 10 times more intensive than Russia. This is explained, first, by the structure of the manufacturing sector in the country, mainly represented by the energy intensive aluminium production. Second, irrigation is the third largest consumer of electricity in the area, accounting for 20 percent of the total volume of electricity produced in Tajikistan during the irrigation season.

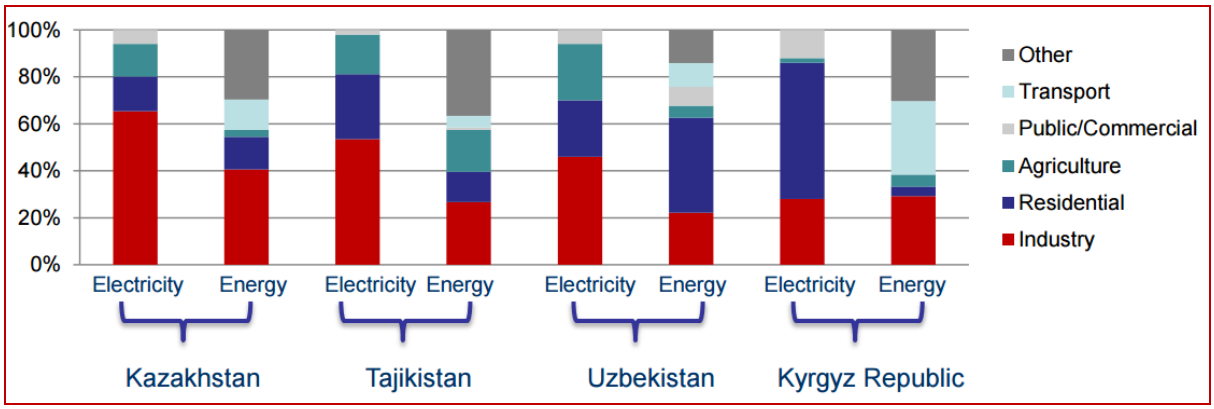

Figure 9. Share of electricity/energy consumption by sectors
Source: Energy Charter Presentation, 2013

3.1. Energy efficiency use in agriculture production

This section analyses data on agriculture inputs received from different sources and also verified through the interviews with five cotton farmers in Kanibadam and B. Gafurov districts of Tajikistan. A convenience sampling method was used in identifying the farmers, as the visits were organized by the Water User Association servicing the area. Nevertheless, the team visited farms in the beginning, middle and tail of the irrigation canals to identify key problems they are facing in terms of water and energy efficiency. In addition, the team has used datasets from the latest national rural vulnerability study surveys, which included 200 households and farmers from the target districts.

Our LCA based analysis of water and energy flows in agriculture production was conducted to identify key determinants of energy and water inefficiency in Sugd oblast. Energy and water ratios in agriculture production are inevitably related to production practices, quantity any type of inputs used and yield of crops. The analysis determined farm gate, as a system boundaries and have, thus, excluded processing of agriculture row products into final consumer goods. Cotton was identified, as a crop of interest, given that it consumes the most amount of energy and inputs if compared to other crops, grown in the area.

Energy output-input analysis is performed to understand the scope of energy use efficiency of cotton. As LCA is based on analysis of all the material and environmental flows consumed or emitted in the production cycle, we simplified this approach and focused only on material flows instead. All the inputs and outputs were calculated per ha and entered into Excel spreadsheets. Further, we have identified the metabolizable energy equivalents of these inputs and outputs using extensive literature available on this topic (Yilmaz, Akcaoz, & Ozkan, 2005).Unfortunately, we could not locate any detailed energy censuses for the Central Asia region, that would enable to operate with more specific energy equivalents for each agriculture input used in the agriculture process, hence had to rely on the similar studies conducted in dry arid or semi-arid agriculture zones in other parts of the world. Energy use efficiency indicator, measured as output-input ration was calculated, as a result. (Equation 1.).

$$Energy\ Use\ Efficiency = \frac{Energy\ Output(\frac{MJ}{ha})}{Energy\ Input\ (\frac{MJ}{ha})}$$

$$Energy\ Productivity = \frac{Cotton\ Output\ \left(\frac{kg}{ha}\right)^2}{Energy\ Input\ (\frac{MJ}{ha})}$$

Figure 10 offers a graphical illustration of the system of analysis.

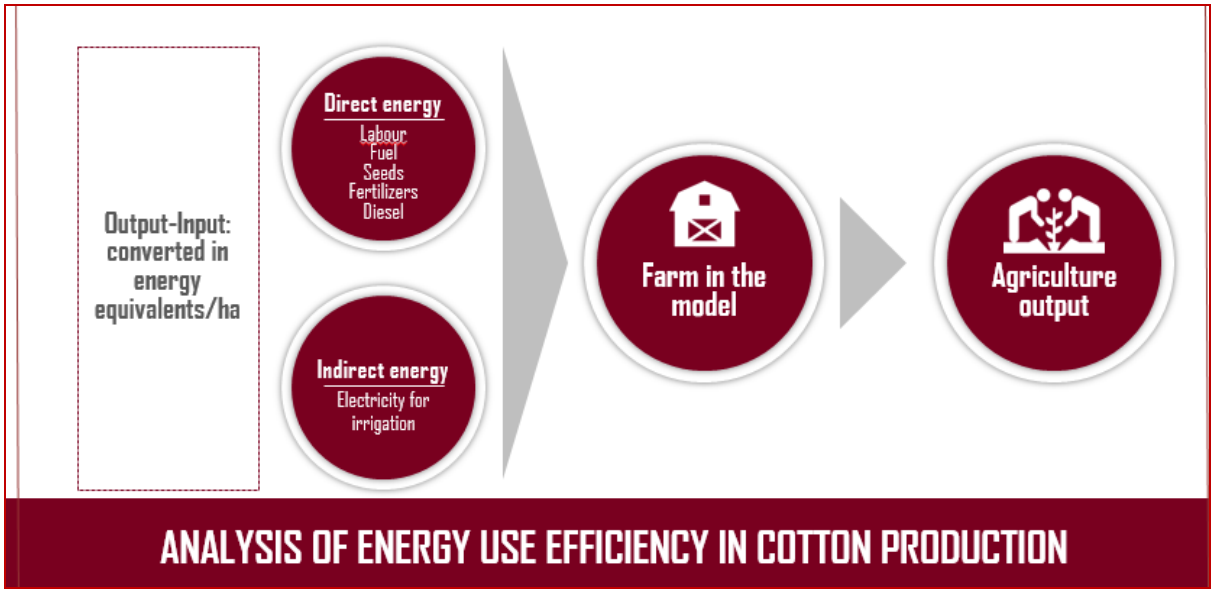

Figure 10. Analysis of energy use efficiency in cotton production

3.1.1. Classification of inputs into direct and indirect energy inputs

For the purposes of our analysis, energy inputs were divided into direct and indirect. Direct energy inputs for agriculture production include mechanical power and fuel, electricity and human power which are usually accounted for by farmers; indirect energy inputs include fertilizers, pesticides, machinery and hidden energy flows that are not obvious to the farmer. However, this distinction between the direct and indirect energy inputs is not clear, when talking about irrigation. Cost of electricity for pumping water from the adjacent canal by private pumps is covered by the individual farms and accounted as direct input, while pumping of water to feed into the main magisterial canal is under responsibility of the Irrigation Authority and is captured in the irrigation fees, partially subsidized by the Government.

While share of agriculture in the total gross output is decreasing, more pressure is shifted to the existing producers to achieve substantial increases in food production through the more intensive use of fossil fuel chemical fertilizers, pesticides, machinery and electricity.

Globally, energy consumption of agriculture sector, has increased. Limited arable land resources, heavily subsidized agriculture inputs and lack of knowledge about more efficient energy inputs lead to situations where resources are allocated ineffectively.

Economic analysis of energy efficiency of cotton production in the similar climate conditions was done in Turkey (Yilmaz et al, 2005) and arid zones of Iran (Zahedi et al, 2014). The research adopted estimates of energy equivalents given provided earlier by Sing (2000 and 2004), Tsatsarellis (1991) and Stount (1990). The analysis has also benchmarked the received energy efficiency ratio with the findings of other studies conducted in the arid-zone climate. Findings of our literature review are presented in Table 3.

3.1.2 Results and discussion

On average, a typical individual farm in Sugd oblast has from 0.8 to 3 ha of land, out of which usually not less than 50 percent of land is allocated under cotton production. About 90 percent of all the land is irrigated, and in addition to cotton, farmers grow wheat, orchards and barley. Farms in Tajikistan use very little amount of fertilizers and pesticides due to the high cost of these inputs and their constrained availability. Farmers mainly rely on rented old machinery for planting and sowing seasons. Harvesting of cotton is a manual labor intensive process. Average labour used in cotton production was estimated at 563 hours per hectare.

Cotton fields are irrigated 6 times during the whole cultivation process. Usual water requirement of cotton is estimated at 6,000 to 8,000 m^3. The results of our analysis shows that the total energy consumed per ha of land under cotton is estimated at around 57,492 MJ/ha. Detailed calculations are shown in Table 4.

Table 2. Literature review and summary of energy equivalents for agriculture inputs

Input (unit)	Energy equivalent (MJunit−1) per ha of cotton farm							
	(Yaldiz, Ozturk, Zeren, & Bascetincelik, 1993)	(Singh, Singh, & Singh, 2004)	(Shrestha, 1998)	(Yilmaz, Akcaoz, & Ozkan, 2005)	(Zahedi, Eshghizadeh, & Mondani, 2014)	(Tsatsarelis, 1991)	(Meul, Nevens, Reheul, & Hofman, 2007)	**Average**
Chemicals (kg)	101.2							**101.20**
Insecticides (kg)							278	**278.00**
Fungicides (kg)							276	**276.00**
Human power (hr)	1.96			2.3	1.95	1.96		**2.07**
Machinery (hr)		62.7			62.7	41.4		**62.70**
Nitrogen fertilizer (kg)			66.14	64.4	75.46			**68.67**
Phosphorus (kg)			12.44	11.96	13			**12.47**
Potassium (kg)			11.15		11.15			**11.15**
Seeds (kg)		11.8			11.8			**11.80**
Electricity for irrigation (kWh/m3)								**2.30**
Water for irrigation (m3)	0.63				1.02			**0.83**
Diesel (l)		56.31		56.31	56.31			**56.31**
Gasolin (l)								**32.20**

Table 3. Inputs required per ha of cotton production

#	Inputs	Physical input				Energy equivalent, MJ	
		Unit	**Q-ty**	**Comments**	**Source of inf.**	**Energy equivalent per unit, MJ**	**Total Energy Required/ha**
1	**Human labor**						**1,165.41**
1.1.	Land preparation	h	5	Preparation works (Irrigation furrows etc), per 1 hour 0,2 ha	2	2.07	10.35
1.2.	Cultivation and etc.	h	135	Approximate. Per 1 hour: cleaning of seedlings - 0,03 ha; weeding ~ 0,025 ha - 2 times; removing of top foliage ~ 0,05 ha.	2, 3	2.07	279.45
1.3.	Irrigation	h	86	Average 6 irrigation, average ~ 0,07 ha per 1 hour of irrigation	2, 3	2.07	178.02
1.4.	Mannual application of chemicals	h	5	Approximate per 1 hour ~ 0,2 ha	2	2.07	10.35
1.5.	Harvesting	h	320	Approximate. Average estimation per 1 hour 8 kg (Depending on time from ~ 5 to ~ 9 kg)	1, 2	2.07	662.40
1.6.	Cleaning the land from stables	h	12	Approximate. Per 1 hour ~ 0,08 ha	2	2.07	24.84
2	**Machinery**						798.00
2.1.	Ploughing	h	2	Approximate. Per 1 hour machinery processes ~ 0,6 ha	2	22.8	**45.60**
2.2.	Levelling, chiselling	h	1	Approximate. Per 1 hour machinery processes ~ 1,3 ha. As well application of fertilizers	2	62.70	62.70

2.3.	Furrowing, Sowing	h	1	Approximate. Per 1 hour machinery processes ~ 0,8 ha	2	62.7	62.70
2.4.	Cultivation	h	6	Approximate. 5 cultivations is required, per 1 hour machinery process from ~ 0,8 to ~ 1,2 ha. Chemicals and fertilizers are applied during cultivations	2	62.7	376.20
2.5.	Tillage	h	1	Approximate. Per 1 hour machinery processes ~ 1,5 ha	2	62.7	62.70
2.6	Other machinery works	h	1	Uprooting etc.	2	62.7	62.70
2.7.	Transport	h	2	Approximate estimation of transportation of inputs and harvest		62.7	125.40
3	**Chemical fertilizers**						**27,640.83**
3.1.	Nitrogen	kg	350	200 kg Ammonium nitrate, 150 kg Urea	1	68.67	24,033.33
3.2.	Phosphorus	kg	150		1	12.47	1,870.00
3.3.	Potassium	kg	50		1	11.15	557.50
4	**Seed**	kg	100		1	11.80	**1,180.00**
5	**Chemicals**			MoA estimated cost of chemicals is 50 USD per ha			**484.50**
5.1.	Pesticides	kg	1		3	276.00	276.00
5.2.	Insecticides	kg	0.75		3	278.00	208.50
6	**Diesel and oils**						**17,376.80**
6.1.	Diesel	l	280		1	56.31	15,766.80
6.2.	Fuel	l	50		1	32.20	1,610.00
6.3.	Diesel oils	l	12		1		-

6.4.	Atol	l	2		1		-
6.5.	Nigrol	l	2		1		-
6.6.	Solidoil	l	1		1		-
7	**Water for irrigation**	m3	6000	Average 6000-8000 m^3 for 6 times of irrigation	2		**8,847.36**
8	Electricity for irrigation	kW	3840		4, 5	2.30	8,847.36
Total energy input in production stage							**57,492.90**
Cotton yield		**Kg/ha**	**2300**	**Inputs costs calculated based on expected yield as 2,3 Mt per ha**	**1**	**11.80**	**27,140.00**

Source:

Ministry of Agriculture of the Republic of Tajikistan. Calculation of cotton growing cost per 1 ha, Dushanbe 2005

Growing cotton (Хлопководство), Moscow 1983. Detailed technology map of growing cotton, p. 308

WB farm surveys (2012, 2014)

UNESCO (2010) Water footprint of agriculture in Central Asia. **http://waterfootprint.org/media/downloads/Report41-WaterFootprintCentralAsia_1.pdf**

World bank (2015). Irrigation Efficiency Study, Unpublished

Notes: Methodology. Most of recent studies of cotton growing situation in Tajikistan are mainly focused on the costs of inputs/services rather than duration of particular work of service. Therefore, it is difficult to estimate the duration of machinery services and human labor based on current data. In this table for Machinery and Human labor usual types of works listed as per WB farm surveys [3] and approximate duration shown as per detailed technology map from [2]. For other inputs the primary source is MoA data [1].

The agricultural practices performed in cotton production in the area has been shown in Table 4. The tilling of land is performed twice between the months of October and November. Thereafter, four rounds of thinning is performed between the months of February and March, the cotton seed is sown in March-April. Cotton is irrigated by the "wild irrigation method" about 6 times between May and September. Fertiliser is applied approximately 2 times within the March-July term. Plant protection is started in April and ends August with the very limited pesticide and herbicide application. Generally the cotton crop is dug two times by hand and four times by machine during the months from March to July. After the process the cotton can be harvested atleast twice between September and October which is also called "Chinak" by locals.

It has been estimated that production of one kilogram of cotton may require an energy input of approximately 25 MJ. A majority of the input comes from nitrogen fertilizer followed by diesel and water. In 2014, cotton production covered in Sogd oblast of Tajikistan was estimated at 417,977 metric tons. Estimated energy consumed for this volume of production is 1.04 GJ.

The energy efficiency indicator is best expressed as the ratio of energy use efficiency per cultivated area, or energy output by energy input (Equation 1), estimated at 0.4 for the small farm with an average yield of 2.3 Mt/ha. Comparison of this indicator with the findings of similar studies reveal low energy use efficiency in cotton production in the research area. Energy productivity is also low compared to other cotton-growing countries (Table 5). Low value of energy use efficiency ratio means high inefficiency in the system, meaning that highly energy intensive process yields low energy-equivalent output. The analysis of energy efficiency of cotton production does not include the amount of electricity and fuel required to run the drainage pumps, mainly operated by the State Agencies.

Table 4. Benchmarking energy inputs kWh/ha in cotton production systems in Greece, India, Iran, Turkey

	Greece	India	Iran	Turkey	Tajikistan
Energy use Efficiency	0.76	1.47	0.62	0.76	0.47
Energy Productivity	0.06	0.12	0.05	0.06	0.04

Direct energy (Mj/Ha)	61100		35865	21141	18542
Indirect energy (MJ/ha)	8500		16642	28595	38950
Total energy	**69,600**	**10,869**	**52,507**	**49,736**	**57,492**
Average Yield (kg/ha)	4500	1355	2738	3187	2300

Source: Compiled from multiple sources

The energy use efficiency ratio is one of the lowest compared to other countries with similar characteristics. The key determinants of energy inefficiency are chemical fertilizers, diesel and oils and electricity for irrigation. Consumption of electricity for irrigation accounts for 18 to 35 percent of total energy inputs used. This supports the findings of the conclusion in the previous chapter. We have also conducted a sensitivity analysis for the energy output-input ratios result in response to changes in agriculture productivity and water consumption. The testing range for the agriculture productivity scenarios varied from 1.8 t/a in Asht district an 2.3/ha in Kanibadam.

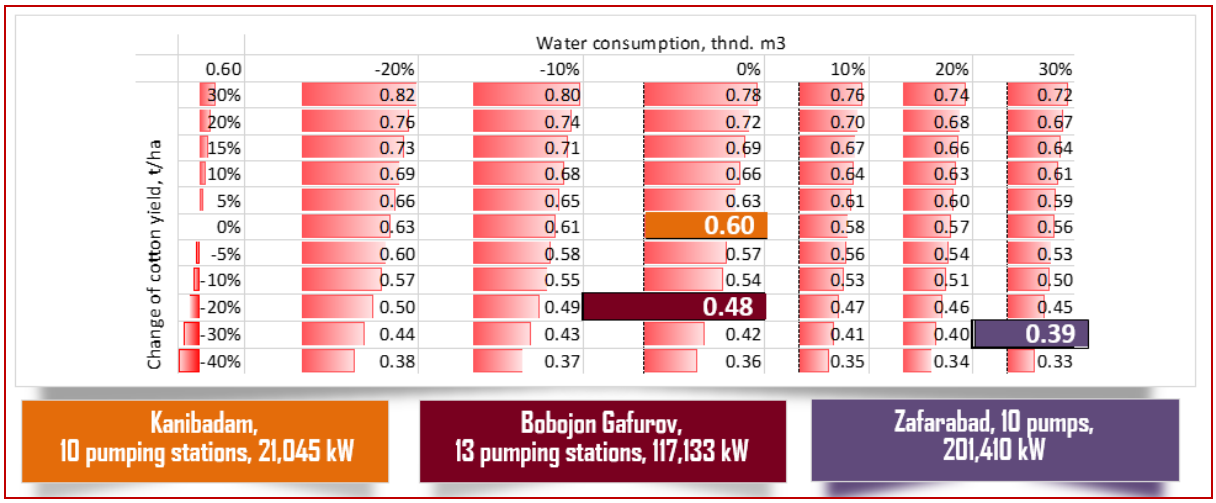

Figure 11. Sensitivity analysis of energy use efficiency of two factors

Chapter 4. Policy Recommendations

During our field trip we spoke to a wide spectrum of stakeholders with varied interest areas. This helped us gauge the problems and suggest recommendations accordingly. The questions were categorized under three major categories which had specific

recommendations under them. The categories and the specific recommendations with the percentage of stakeholders suggesting them are the following

1. Irrigation infrastructure
    a. Modernization of irrigation infrastructure – 60 %
    b. Replacement and rehabilitation of pumps – 80%
    c. Installation of meters/outlet gates – 70%
2. Financing for efficient technologies
    a. Increasing authority of WUA's – 50%
    b. Raising awareness and improving local capacity – 50%
    c. Diversification of agriculture – 60%
3. Financial Solutions
    a. Rationalizing policy and subsidy policy – 60%
    b. Providing incentives for adoption of new technologies – 60%

The above suggestions were then evaluated on the basis on the eight criteria discussed in Chapter 2. Impact on each criteria was measured with Low, Moderate and High and a score of 1, 2 and 3 was assigned for the impact levels. As listed earlier, the criteria are as follows

1. **Effects**
    a. **Water Efficiency**
    b. **Energy Efficiency**

c. **Food Production**

d. **Equity**

2. **Implementation**

a. **Acceptability**

b. **Technical Feasibility**

c. **Financial Feasibility**

All the above recommendations would now be discussed with respect to these criteria.

1. **Replacement of old pumps:** Many pumps have been operational since the Soviet era and have not been replaced since then. The pump technology has advanced a lot since then, which means that the modern pumps would consume far less electricity when compared to pumps designed 4 to 5 decades ago. Replacing old pumps with efficient and new pumps which have been designed on the basis of latest technology would mean that country would have more electricity to export or divert to other productive use. However, two major challenges of financial visibility and technical knowhow can become a huge burden towards implementation of the proposed measures. The government may not have the necessary financial resources to replace existing pumps with modern pumps, operation of which may also require training and capacity building at the local level. Hence we observe that this may have low effect towards increasing water efficiency since water usage does not depend on the efficiency of pumps, it would have moderate to high effects on energy efficiency since orthodox pumps would be replaced with new ones. The intervention would also have moderate effect on increase in food production and equity since replacement of pumps would mean low downtown time. While political acceptability would be low, other stakeholder acceptability would be very high. Local capacity building may be required before the pumps are replaced which means that the technical feasibility is low. Financial feasibility may be from low to moderate due to huge upfront investment required. The financial feasibility may increase once other financing mechanisms are explored.

2. **Rehabilitation of existing pumps:** Instead of replacing existing pumps, replacement of pumps can also be suggested. This would reduce the requirement of high upfront investment for the intervention. Hence we observe that this may have low effect towards increasing water efficiency since water usage does not depend on the efficiency of pumps and pumps would be rehabilitated and not replaced with efficient and modern ones. This would though have high effect on energy efficiency since pumps would be rehabilitated. The intervention would also have moderate effect on increase in food production and equity since replacement of pumps would mean low downtown time. While political acceptability would be low, other stakeholder acceptability would be very high. Since the pumps have already been operating, this option may not require lot of capacity building which means the technical feasibility is high but the financial feasibility is moderate since pumps rehabilitation of pumps is associated with lower level of initial investments. However, in many cases rehabilitation will only bring incremental benefits, due to inefficiency of the pumping system as a whole.
3. **Rehabilitation of irrigation network:** Irrigation network is not designed efficiently which often leads to wastage of water, higher intensity of pumping and decrease in availability of water for many farmers. Cleaning and lining of irrigation network would lead to increased flow of water to water-scarce areas, especially those towards end of the canals or just before the pumping stations and reduction of losses to infiltration and seepages. This would have a moderate effect on enhancing water efficiency, energy efficiency and increasing food production. Due to improved availability of water to farmers who earlier faced a lot of problems, the equity of water distribution is expected to improve. The acceptability of all stakeholders towards the intervention would also be very high. Given that the farmers have been using the existing infrastructure for a long time, it would take some time and effort to design the new network which means that the technical feasibility to implement the solution is of moderate level. The cost to modernize the irrigation network would not be huge which means that the financial feasibility to implement the solution is moderate. The proposed policy should be accompanied with improvements in water distribution infrastructure, including water outlet gated, measurement devices, etc.

4. **Stronger institutional capacity of WUAs**: It has often been suggested that WUA's have not been provided sufficient autonomy to take decisions and do not have a lot of control over on-farm water management on their territory. For instance, they cannot penalize farmers for irrational use of private pumps. Strong and socially representative WUAs will have capacity to establish and enforce irrigation schedules, that would increase equity in water allocation and efficiency of water use. We acknowledge that strengthening capacity of WUAs is a controversial process, which triggers vested interests of different stakeholders. Some of the stakeholders, including the large farms and district level irrigation departments may lose some power due to empowerment of WUA's. It is important to include WUAs in the water sector as equal partners and assist them in building technical capacity. Empowerment of WUA's requires passing a legislation which may take some time. It may also require capacity building at the WUA administration level and hence the technical feasibility may be moderate. However, this process would not require much financial assistance which means that the financial feasibility to implement it is very high. The proposed policy is supposed to bring substantial changes in on-farm irrigation management; however, off-farm irrigation will still remain a main challenge for the sector.

5. **Increasing awareness about technologies:** It was observed that farmers and even WUA's were not aware of the latest farming technologies like drip irrigation. While drip irrigation is seen as an expensive innovation for Tajik agriculture, increasing awareness of farmers of this technology would enable farmers to better prepare for the anticipated shocks of water supply. about farming technologies. This effort could help farmers by reducing their requirement of water and electricity since new technologies are highly efficient. New technologies can also help farmers make better decisions regarding their crops. However, given that it is only awareness, proposed policy would have low effects on increasing food production or improving water and energy efficiency in the short run. However, the acceptability of this recommendation would be very high since farmers would be interested to know more about new technologies. The technical feasibility and financial feasibility would

also be very high since this would require much technical knowledge, training and financial resources to disseminate information

6. **Diversification of crops:** Most of the farmers focus on cotton, wheat and fruit orchards; however, economic potential of growing other crops in the area should be also explored and assessed from the water-energy-food efficiency perspective. Creating a market for new crops, providing the necessary support like seeds, training and awareness about growing alternative crops can help farmers in big way. These crops can either be consumed locally or be exported. Diversifying crops can have moderate positive effects on water efficiency since the new crops would be consuming less water when compared to cotton, hence required effect on energy efficiency is supposed to reduce as well. Diversification can also lead to high impact on food production and equity. At the same time, a recent Freedom to farm decree (Government of Tajikistan, 2009) resulted only in incremental changes in ccropping patterns of farmers. Most of the farmers will not consider shifting from cotton to other crops, as it will compromise their income. Cotton growing remains a profitable business, with the opportunities of storing and processing commodity domestically in times of cotton price crisis. From the strategic point of view, the Government should maintain the level of its foreign revenues, already severely damaged by reduction in remittances. Technical feasibility may be high since it may be easier to suggest new crops based on soil condition and water availability. However, financial feasibility may only be moderate because the value chains for other crops are yet to be established.

7. **Installation of meters at gates:** Installation of water meters can lead to increase in accountability for usage of water leading to reduction in wastage. However, given that water to farm is not metered, any process of metering can lead to huge backlash from farmers since they would think that the next step is charging them on basis of quantity of water used. Hence the acceptability of the idea may be very low among farmers. Taking this step can lead to increase in water efficiency and can also increase food production, as more rational irrigation practices will be incentivised. However, the effect on energy efficiency may not be enough. Installation of meters

can also lead to increase in equity. While technically it may be easier to install meters at gates, without sufficient support base financing of the proposed measure may be challenging.

8. **Rationalizing Subsidies:** As discussed in the chapters above, current subsidies channeled to the irrigation sector are harmful both for the public and private sector. Gradual change of the existing subsidies policy is recommended. In fact, subsidies, could be diverted to encourage private sector participation in the sector. This would create a better business environment for innovations in the sector and improving its efficiency. However, as burden of the subsidy in this scenario would need to be reallocated to farmers, the proposed policy may trigger negative response from the public. Hence the acceptability of such a decision would be very less across various stakeholders. The proposed policy would probably have a large impact on water and energy use efficiency, but only when combine with improvements in the quality of irrigation service and accountability in the sector. The effect on food production may be moderate since farmers may have to reduce their water and energy consumption which can potentially impact the production. Changes in the subsidies policy would tailor further support to the low-income small farms and include differentiated tariff scheme. The effect on equity in this case would be moderate The technical feasibility of such a decision would be moderate since the government would have to install meters across the country which would require huge initial investment.

The table below lists all the recommendations and tries to compare them using a score of 1 for Low, 2 for Moderate and 3 for High. Summarizing the Table we observe that increasing awareness about new technologies, diversification of crops and modernization of the irrigation network may be the three most effective interventions in the short term. However, these interventions may not yield expected results, if more complex irrigation sector reforms are not implemented.

Table 5. Evaluation of the proposed policies

Criteria	**Replacement of Pumps**	**Rehabilitation of Pumps**	**Modernization of Irrigation Network**	**Stronger WUA**	**Increasing awareness about new technologies**	**Diversification of crops**	**Installation of meters**	**Rationalisation of subsidies**
Water efficiency	Low	Low	Moderate	Moderate	Moderate	Moderate	High	High
Energy efficiency	High	Moderate	Moderate	Low	Moderate	Low	Low	High
Food production	Moderate	Moderate	Moderate	Low	Low	High	High	Moderate
Equity	Moderate	Moderate	High	High	Moderate	High	High	Moderate
Acceptability	High	High	High	Moderate	High	Moderate	Low	Low
Technical Feasibility	Low	High	Moderate	Moderate	High	High	Moderate	Moderate
Financial Feasibility	Moderate	Moderate	Moderate	High	High	Moderate	Low	Low
Total Score	**14**	**15**	**16**	**14**	**16**	**16**	**15**	**14**

Conclusions

We have analyzed eight policy recommendations for improving water and energy efficiency in agriculture production in Sugd oblast. The evaluated policies are not mutually exclusive and have a reinforcing effect on each other. This is in line with the broader context of natural resources management, in which most of the policy questions are multi-dimensional and complex by nature. It should be noted that the report did not aim to produce optimization models or look at the best allocation of resources, but rather intended to flag the importance of system thinking in designing the policies within the water-energy-food nexus. The report is prepared to look at the existing and proposed agricultural policies in a systematic way. In this attempt we tried to make it as analytically comprehensible as possible, taking three metrics in our assessment - physical, monetary and distributive.

Recent agriculture policy reforms in Tajikistan, generated enormous impact and pressure on other resources. For instance, land reform process implemented in isolation of the irrigation sector in Sugd oblast led to deterioration of the on-farm irrigation infrastructure and lack of financing from the public sector. Despite the close relationship of water, food and energy resources, their funding and decision making are managed as separate issues across the spectrum of policy, planning, design and operation. Now - as a new set of water sector policies and energy projects are emerging, it is a time to consider the bordering areas of water and energy use.

However, implementability of the proposed policies depends on the range of factors, also discussed in the chapter above. Due to study's limitations, all the eight criteria used for evaluation of the policies were assigned equal weightage. This could lead to a biased ranking of the policies and lead to a rejection of the policy with the highest impact. For instance, rationalization of the subsidy seemed very attractive and justifiable by the process, but very low acceptability of the option ruled out the possibility of its implementation. Hence, while the report did not assign specific weightage to various criteria, it was pragmatic in this approach while suggesting the necessary policy recommendations to increase water and energy use efficiency in agriculture sector. Further research connecting WEF interlinkages between individual provinces or even smaller units of anlaysis is required to model these relationships as sub-systems.

Annex 1. People met during the PAE Field trip

1. Mr. Shuhrat Igamberdyev, Water Cluster Coordinator, UNDP Energy and Environment Programme
2. Mr. Rahmonkul Rahmatulloev, former M&E expert for the WB-funded Ferghana Water Resources Management Project
3. Ms. Nargis Yuldosheva, Head, NGO "Source of Life"
4. Mr. Dusmatov Rahmatullo, Hydro engineer, former water admin
5. Mr. Yakubjon Nabiev, Yavan Water Administration Hydro-engineer, Yavan
6. Mr. Bunyod Yodgorov, Programme Officer, OXFAM, Water Use Efficiency Program
7. Mr. Bobojon Yatimov, Senior Rural Development Specialist, World Bank Country Office, Task Team Leader for the PAMP II
8. Mr. Kabirjon Kabutov, Director, National Institute of Renewable Sources of Energy
9. Mr. Ben Hell, EU, Natural Resources Cluster Coordinator
10. Ms. Makhfirat Abdullaeva, National Team Leader, Rural Water Supply and Sanitation Ferghana Valley, International Secretariat for Water
11. Mr. Dhruva Mani Paudel, Senior Engineer, Rural Water Supply and Sanitation Ferghana Valley, International Secretariat for Water
12. Ms. Rohbar , Social Mobilization Specialist, Rural Water Supply and Sanitation Ferghana Valley, International Secretariat for Water
13. Mr. Asror Matosimov, Agronomist, former specialist on Ferghana Valley Water resources Management Project
14. Mr. Abdumumin Vahobov, Head, Department of water administration, Kanibadam district
15. Mr. Aliboy Ergashev, Head, WUA "Kavsari Kandi Kuhan"
16. Mr. _____, Head, WUA "Mirzomalik"
17. Mr. Komiljon Kholmatov, Farmer
18. Mr. Nasib Dehkonov, Farmer
19. Mr. Ahror Ergashev, Farmer
20. Mr. Kurbon Dadaboev, Farmer
21. Ms. Zarrina Mirzoboeva, Project Officer, Water User Association, National Water resources Managemnt Project, Helvetas
22. Mr. Akram Kamolov, Agronomist-consultant, NEKSIGOL Mushovir
23. Ms. Shahlo Atabayeva, Business Development Specialist, NEKSIGOL Mushovir
24. Ms. Yvonne_____, Un FAO Country Office
25. Mr. Viorel Gutu, FAO Representative in Tajikistan, UN FAO
26. Ms. Shahlo Rahimova, SDC

Annex 2. Pictures from the field trip

Figure 12: Interview with the Apricot farmer in Kanibadam

Figure 13: Cotton field in Kanibadam

Figure 14: Cotton Field in Kanibadam

Figure 15: Interview with Apricot farmer

Figure 16: Interview with farmer in B. Gafurov

Figure 17: Segregated electric supply for farm and residence

Figure 18: Earth canals and small private pumps (BFC)

Figure 19: Mahram Pumping Station

Figure 20: Meeting with the Head of Irrigation Department - Kanibadam

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